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Assumed–Stress Hybrid Elements with Drilling Degrees of Freedom for Nonlinear Analysis of Composite Structures (NASA Grant NAG–1–1505)

Technical Progress Report

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by the

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NAG–1–1505 Progress Report for Second Year

This grant represents a continuation of the research effort initiated by the principal investigator while at Clemson University under NASA Grant No. NAG–1–1374. After the principal investigator relocated to the Old Dominion University, the research effort was renewed and initiated at ODU under NASA Grant No. NAG–1–1505. As such, this research thrust has been underway for approximately two years. Progress under this phase of the grant was reported in an oral presentation to the Computational Mechanics Branch at NASA Langley Research Center on June 30, 1994 (copy on presentation charts are attached).

Specific research objectives for the second year (first year at ODU) were as followed:

- Extend the 2–node assumed–stress hybrid beam element to handle geometrically nonlinear problems using both low–order and high–order corotation approaches.
- Develop a compatible 3–node assumed–stress hybrid shell element with drilling degrees of freedom with capabilities for linear stress, buckling and vibration analyses.
- Validate the combined use of the assumed–stress hybrid 1–D and 2–D elements for modeling built–up structures.
- Extend the 2–D assumed–stress hybrid shell elements to handle geometrically nonlinear problems using both low–order and high–order corotation approaches.
- Examine the drilling freedom formulations based on Allman–type shape functions and on the unsymmetric stress tensor.

The research effort has focussed primarily on completing a more thorough assessment of the assumed stress hybrid formulation by examining different assumed stress fields, on deriving diagonal mass coefficients for the beam and quadrilateral shell elements, and for preparing to move into the area of geometric nonlinear response prediction.

The assessment of different assumed stress fields and the performance of the element for linear stress, buckling, and free vibration analyses has been completed and is reported in a paper submitted to the International Journal for Numerical Methods in Engineering (under review, copy attached). In addition, the "cost" of using this advanced multi–field element has been assessed and compared with other 4–node elements. Significant computational savings have been accrued by using a combination of symbolic integration procedures and numerical analysis routines. These results are reported in a paper which has been submitted, reviewed, and accepted for publication in the Communications in Numerical Methods for Engineering (copy attached).

Another assessment problem was associated with a large finite element model of a shear buckling problem. A significant amount of time was allocated to applying the beam and quadrilateral shell elements to a NASA customer application problem – Grumman shear buckling composite panel. The original analysis was carried out by Dr. Larry Sobel of Grumman using the STAGS elements in COMET. Difficulties were encountered by Dr. Sobel in performing the analysis. These new results did not correlate with his existing results, and it was unclear whether the difficulties were associated with the STAGS element implementation in COMET, the nonlinear analysis procedure, or some other modeling issue. However, when analyzed using the elements developed under this research grant, linear stress and buckling results were obtained that matched both other analytical results as well as results obtained from experiment. Eventually an implementation error was detected in the STAGS shell element kernel routines.

Next steps were taken to validate the nonlinear solution procedure available in COMET's CLAMP procedure `nl_static_1`. Solution to small test problems appeared to be readily obtained and accurate. However, application to large stiffened composite panels led to convergence problems in the postbuckled region of the response. Numerous test cases and example problems were analyzed; yet the same convergence difficulties could not be duplicated except with the large model. This large model had many complicating features including multi–point constraints. A definitive resolution to this problem was not found; although, issues related to the modeling strategy were raised and were to be considered by the NASA engineers. Even though this activity consumed a large amount of time and produced little direct benefit for the research thrust of the grant, it did provide a thorough assessment of the nonlinear solution procedure and its performance which is an integral part of the research.

A supplement to the grant enabled an exploratory study of the adaptive dynamic relaxation algorithm for three–dimension hyperelastic nonlinear structures on massively parallel processing (MPP) systems. This method exploits the advantages of explicit time integration for both static and transient dynamic analysis of structures. The algorithm has been shown to be very scalable as the number of processors increases, has minimal memory requirements for each processor, and minimizes the interprocessor communication. For example on the Intel Touchstone Delta MPP system with 512 processors, a relative speed–up of 386 was obtained. Results from this study are summarized in a paper submitted to the International Journal for Numerical Methods in Engineering (copy attached).

The current research thrusts of the grant are focussed on extending the beam and quadrilateral shell element to problems with geometric nonlinearities and to the development of a compatible 3–node triangular shell element. In addition, supplemental work related to the interface element is underway by Dr. M. A. Aminpour.

Attachments

1. Knight, Jr. , N. F.: "Assumed–Stress Hybrid Elements with Drilling DoF for Nonlinear Analysis of Composite Structures." Grant Review Presentation to Computational Mechanics Branch at NASA Langley Research Center, June 30, 1994.
2. Rengarajan, G., Aminpour, M. A., and Knight, N. F., Jr.: Improved Assumed–Stress Hybrid Shell Element with Drilling Degrees of Freedom for Linear Stress, Buckling, and Free Vibration Analyses. Submitted to **International Journal for Numerical Methods in Engineering**, December 1993.
3. Rengarajan, G., Knight, N. F., Jr., and Aminpour, M. A.: Symbolic Computations in an Assumed–Stress Hybrid Shell Element with Drilling Degrees of Freedom. To appear in **Communications in Numerical Methods in Engineering**, 1994.
4. Oakley, D. R. and Knight, N. F., Jr.: Nonlinear Structural Response using Adaptive Dynamic Relaxation on a Massively Parallel Processing System. Submitted to **International Journal for Numerical Methods in Engineering**, May 1994.